

Attorney Docket No. 83307
Customer No. 23523

OSCILLATING APPENDAGE FOR FIN PROPULSION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT THOMAS J. GIESEKE, citizen of the United States of America, employee of the United States Government, resident of Newport, County of Newport, State of Rhode Island has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

MICHAEL P. STANLEY
Reg. No. 47108
Naval Undersea Warfare Center
Division, Newport
Newport, RI 02841-1708
TEL: 401-832-4763
FAX: 401-832-1231

2

3 **OSCILLATING APPENDAGE FOR FIN PROPULSION**

4

5 **STATEMENT OF GOVERNMENT INTEREST**

6 The invention described herein may be manufactured and
7 used by or for the Government of the United States of America
8 for governmental purposes without the payment of any royalties
9 thereon or therefor.

10

11 **BACKGROUND OF THE INVENTION**

12 **(1) Field of the Invention**

13 This invention generally relates to a device for
14 generating an oscillating motion from a flexible appendage.

15 **(2) Description of the Prior Art**

16 The current art for compact propulsion systems is varied.
17 Some current concepts for unmanned undersea vehicles are very
18 small and simple vehicles which operate in swarms. Each
19 vehicle contains a small sensor which in itself is not
20 particularly powerful but when combined with the sensors from
21 many other vehicles provides a powerful sensing capability.

22 For a very small vehicle to be feasible, it must include
23 space-efficient and weight-efficient energy storage, energy
24 conversion and propulsion systems. Conventional systems
25 utilize batteries, motors, and propellers for energy storage,
26 energy conversion and propulsion systems, respectively. These
27 systems can be very efficient but have limited power

1 densities. Also, if engineered for performance, the systems
2 can be very expensive and can involve many components which
3 could fail under extended operation.

4 An alternative to the use of propellers is the use of
5 flapping wing-like devices. It has been shown that
6 dynamically-pitching foils can produce many times the lift
7 compared to static foils with the same dimensions.

8 Triantafyllou et al. (U.S. Patent No. 5,401,196) has
9 shown that an optimal oscillation frequency exists which
10 maximizes the lift produced by simple flapping wings.

11 In the Bandyopadhyay reference, "Maneuvering
12 Hydrodynamics of Fish and Small Underwater Vehicles"
13 INTEGRATIVE AND COMPARITIVE BIOLOGY, February 2002 -Vol. 42,
14 it has been further shown that the nature of vortex production
15 from flapping foils controls the efficiency of wings as
16 propulsive devices.

17 Further, in the Dickinson reference, "Wing Rotation and
18 the Aerodynamic Basis of Insect Flight" SCIENCE, 18 June 1999
19 - Vol. 284, it has been shown that the circulation of wings is
20 critical to the enhanced lift production with a low Reynolds
21 number for insect flight.

22 A number of devices have been proposed which attempt to
23 take advantage of the hydrodynamic effects associated with the
24 flapping foil motion commonly seen in fish propulsion and bird
25 flight. However, it is not readily evident that any device
26 has been proposed which is mechanically simple and can be
27 manufactured in quantity at a very low cost.

1 The following patents, for example, disclose types of
2 oscillatory wing devices, but do not disclose a device which
3 produces an oscillatory motion in a flexible appendage, which
4 utilizes pressurized fluid to inflate specially designed tubes
5 within the appendage, and which includes a valve system for
6 automatically distributing the pressurized fluid to the
7 appropriate tubes.

8 Specifically, Gander (U.S. Patent No. 4,389,196)
9 discloses a watercraft, propelled by a swivellable propulsion
10 fin, in which the fin extends from its swivel axle parallel to
11 the longitudinal direction of the watercraft and which is
12 swivellable laterally by a drive device. The swivellable
13 propulsion fin is arranged on the stern of the watercraft in
14 the prolongation thereof.

15 Moscrip (U.S. Patent No. 4,941,627) discloses a hollow
16 fin with a rhombical cross-section constructed of Nitinol or
17 another memory effect alloy, mounted for oscillation about an
18 internal shaft. The memory effect alloy has been previously
19 stretched at a temperature below its critical transition
20 temperature such that heating of one pair of opposite sides,
21 in a rhombic sense, above the critical transition temperature
22 by resistive dissipation of an electric current will cause
23 shortening of this pair of sides and consequent change in the
24 angle of attack.

25 Mostaghel et al. (U.S. Patent No. 5,366,395) discloses a
26 pulsating impeller system moving a body through a fluid
27 medium. The pulsating impeller includes an enclosure mounted

1 on a vessel or other body. The enclosure is provided with an
2 inlet-outlet aperture for the flow of the fluid medium into
3 and out of the enclosure. An expandable membrane is
4 positioned in the enclosure. The volume of the membrane is
5 inflated and deflated on a regular cycle by a compressed air
6 or similar system in the vessel. When the enclosure is placed
7 in a fluid such as water, and the membrane inside the
8 enclosure is inflated and the volume of the membrane is
9 increased, which results in the water being forced through the
10 outlet hole in the enclosure to propel the vessel. This force
11 generates a reactive force which thrusts the enclosure and
12 vessel in the opposite direction.

13 Triantafyllou et al. (U.S. Patent No. 5,401,196)
14 discloses a propulsion system for use in a fluid, the system
15 utilizing at least one foil which is both oscillated at a
16 frequency "f" with an amplitude "a" in a direction
17 substantially transverse to the propulsion direction and
18 flapped or pitched about a pivot point to change the foil
19 pitch angle to the selected direction of motion with a smooth
20 periodic motion. Parameters of the system including Strouhal
21 number, angle of attack, ratio of the distance to the foil
22 pivot point from the leading edge of the foil to the chord
23 length, the ratio of the amplitude of oscillation to the foil
24 chord width and the phase angle between heave and pitch are
25 all selected so as to optimize the drive efficiency of the
26 foil system.

1 Yamamoto et al. (U.S. Patent No. 6,089,178) discloses a
2 submersible vehicle having swinging wings. The vehicle is
3 provided with a main body and rotatable shafts arranged in
4 series and located at front edges of the swinging wings,
5 actuators for driving the shafts independently of one another,
6 and a wing controller for controlling the actuators in such a
7 manner that the wings swing in a flexible manner like the tail
8 fin of a fish.

9 Sagov (U.S. Patent No. 6,500,033) discloses a method for
10 propulsion of water-going vessels comprising a plate, which is
11 located in the water and extends across a desired direction of
12 motion for the vessel, where the plate is moved from a first
13 position to a second position and back. Under the influence
14 of a motive force the extent of which varies sinusoidally, the
15 plate is brought into translatory and rectilinear oscillation
16 about a neutral position between the first and the second
17 position, the neutral position being determined by a static
18 equilibrium between spring forces influencing the plate. The
19 plate is controlled in such a manner that its plane extends
20 perpendicularly to the vessel's direction of motion, and
21 greater resistance is exerted by the plate against the water
22 when it is moved opposite to the vessel's desired direction of
23 motion than when it is moved in this direction.

24 It should be understood that the present invention would
25 in fact enhance the functionality of the above references by
26 providing an oscillating motion by a flexible appendage, the
27 flexible appendage including specially designed tubes embedded

1 therein, and the tubes being manipulated with a supply of
2 pressurized fluid.

3 **SUMMARY OF THE INVENTION**

4 Accordingly, it is a general purpose and primary object
5 of the present invention to provide a device as an oscillating
6 appendage for fin propulsion.

7 It is therefore a further object of this invention to
8 provide an oscillating appendage with motion as the result of
9 action by pressurized fluid.

10 It is therefore a still further object of the present
11 invention to provide an oscillating appendage in which a
12 selector valve alternates a supply of pressurized fluid to a
13 selected portion of the appendage.

14 In accordance with one aspect of the present invention,
15 there is provided an oscillating appendage including a
16 pressure vessel housing a supply of pressurized fluid,
17 reinforced tubes selectively receiving fluid pressure from the
18 pressure vessel, a valve for controlling the supply of
19 pressurized fluid from the pressure vessel to the reinforced
20 tubes, and a flexible skin encompassing the pressure vessel,
21 the reinforced tubes, and the valve. The flexible skin
22 defines an outer shape of the oscillating appendage and a tail
23 member is affixed at a terminal end of the oscillating
24 appendage to propel the appendage when the appendage
25 oscillates. The valve is operated to supply pressure to one

1 or the other of the reinforced tubes, thereby selectively
2 directing the movement of the appendage.

3 **BRIEF DESCRIPTION OF THE DRAWINGS**

4 The appended claims particularly point out and distinctly
5 claim the subject matter of this invention. The various
6 objects, advantages and novel features of this invention will
7 be more fully apparent from a reading of the following
8 detailed description in conjunction with the accompanying
9 drawings in which like reference numerals refer to like parts,
10 and in which:

11 FIG. 1 depicts a top cross-sectional view of a flexible
12 appendage according to a preferred embodiment of the present
13 invention with the appendage in a neutral position;

14 FIG. 2 depicts a top cross-sectional view of the flexible
15 appendage of the present invention with the appendage in a
16 flexed position;

17 FIG. 3 depicts a top cross-sectional view of the flexible
18 appendage of the present invention with the appendage in an
19 opposing flexed position;

20 FIG. 4 is a sectional view of a valve for use in the
21 flexible appendage of the present invention; and

22 FIG. 5 is a sectional view of a reinforced tube for use
23 in the present invention.

24

1 **DESCRIPTION OF THE PREFERRED EMBODIMENT**

2 In general, the present invention is directed to a
3 propulsion device in which the propulsion is created by an
4 oscillatory motion in a flexible appendage. Such a flexible
5 appendage 10 is generally shown in FIGS. 1, 2 and 3 in neutral
6 and opposingly flexed positions.

7 Specifically, the flexible appendage 10 includes a
8 pressure vessel 12 which contains pressurized gas or fluid as
9 a system driver for the flexible appendage. A valve 14
10 distributes pressurized fluid from the fluid supply in the
11 pressure vessel 12 to reinforced tubes 16. The valve 14 can
12 be externally controlled to distribute fluid through a fluid
13 system of the appendage 10 as desired, or it can be automatic,
14 to distribute fluid in a predetermined fashion. As will be
15 further described, an automatic mechanical system is proposed
16 for simplicity with the detail of the valve 14 further
17 described in connection with FIG. 4.

18 A plurality of reinforced tubes 16 extend from the valve
19 14 to a tail 18 of the appendage 10. The reinforced tubes 16
20 are shown in detail in FIG. 5 and will be further described
21 below for their structure and operation.

22 A spongy and flexible skin 20 is wrapped around the
23 reinforced tubes 16, the pressure vessel 12, and the valve 14
24 to create a body and transmit the movement of the flexible
25 appendage 10. The skin 20 of a type known to those skilled in
26 the art can easily be compressed and stretched during
27 articulation of the appendage 10.

1 Referring to the reinforced tube 16 shown in FIG. 5, the
2 tube includes an inner elastomeric tube 22 which holds
3 pressure and allows axial expansion of the tube. Rigid
4 constraint rings 24 spaced along the tube 16 prevent radial
5 expansion of the inner tube 22. Ideally, the constraint rings
6 24 are thin and closely spaced to prevent herniation of the
7 inner elastomeric tube 22. An end cap 26 closes the end of
8 the inner elastomeric tube 22 and transfers internal pressure
9 to axial tube loading. A combined supply port/end cap 28
10 closes an opposing end of the inner elastomeric tube 22,
11 transfers internal pressure to axial tube loading, and allows
12 pressurized fluid to enter the tube structure 16 by an opening
13 29 in the supply port/end cap. Interconnecting members 30
14 connect one tube 16 to others and/or to a structure so that
15 axial expansion of the tube is transferred into driving
16 motions.

17 Turning now to the oscillating valve 14 shown in detail
18 in FIG. 4, the valve generally includes a casing 32 which
19 houses a spindle 34. The casing 32 also attaches to pressure
20 lines and includes chambers 48, 52 on opposite sides of the
21 spindle 34.

22 The spindle 34 is cylindrically shaped having pass-
23 through lines 36, 38, and 40 formed therein to connect
24 pressures and vents to tubes 16A and 16B. Multiple
25 circumferential seals 42, such as O-rings, are provided to
26 prevent fluid flow from one tube 16A to another tube 16B. A
27 spring member 44 normally biases the spindle 34 to the chamber

1 48. In other words, when the spindle 34 is fully seated to
2 the chamber 48, the spring 44 maintains a force to the chamber
3 due to its preload.

4 A first stop/end-cap 46 closes the pressure chamber 48
5 and includes a stem 49 for terminating motion of the spindle
6 34.

7 A second stop/end cap 50 closes the pressure chamber 52
8 and includes a stem 53 for terminating motion of the spindle
9 34. The first stop/end cap 46 and second stop/end cap 50 may
10 be threaded into an opening in the respective ends of the
11 casing 32 in order to provide a secure fitting therewith.

12 Pressurized fluid is supplied from the pressure vessel 12
13 to the valve 14 through a supply port 54.

14 First vent port 58 connects the tube 16B to ambient
15 pressure when the spindle 34 is fully to the pressure chamber
16 52. A second vent port 56 connects the tube 16A to ambient
17 pressure when the spindle 34 is fully to the pressure chamber
18 48.

19 A pressurization port 60 connects the pressure chamber 48
20 to a pressurization throttle 62. A pressurization port 64
21 connects the pressure chamber 52 to a pressurization throttle
22 66.

23 The pressurization throttle 62 restricts flow from the
24 tube 16B to the pressure chamber 48. More restriction
25 increases the time required to build sufficient pressure in
26 the pressure chamber 48 to force the spindle 34 to the
27 pressure chamber 52.

1 The pressurization throttle 66 restricts flow from the
2 tube 16B to the pressure chamber 52. More restriction
3 decreases the time required to build sufficient pressure in
4 the pressure chamber 48 to force the spindle 34 to the
5 pressure chamber 52. If insufficient restriction is provided
6 from the throttle 66, pressure from the pressure chamber 52
7 will build too quickly and insufficient pressure will be
8 available to force the spindle 34 toward the pressure chamber
9 52.

10 A vent port 68 allows air or fluid built up in the
11 pressure chamber 52 to be quickly vented once motion to the
12 chamber is initiated.

13 A vent passage 70 allows the flow of air or fluid for the
14 pressure chamber 52 through the vent port 68.

15 The vent pass-through line 38 acting as a vent, connects
16 the tube 16B to ambient pressure when the spindle 34 is toward
17 the pressure chamber 52. The vent pass-through line 40, also
18 acting as a vent, connects the tube 16A to ambient pressure
19 when the spindle 34 is toward the pressure chamber 48. The
20 pass-through line 36 acting as a fluid supply connects the
21 tube 16A or the tube 16B to supply pressure when the spindle
22 34 is positioned toward the pressure chambers 52 and 48,
23 respectively.

24 Thus, a mechanical device is proposed for the fluid
25 distribution control. Its design generates an oscillating
26 motion of the spindle 34 alternately connecting the tube 16B
27 and tube 16A with pressurized fluid. When the system is de-

1 energized, all volumes, lines and chambers are filled with
2 ambient pressure fluid. The spindle 34 is forced to the
3 chamber 48 against the stem 49 of the end cap 46 by the
4 preloaded spring 44.

5 To start oscillation of the flexible appendage 10,
6 pressurized fluid is supplied to the supply port 54 and flows
7 through the valve 14 to the tube 16B. As the pressure builds
8 in the tube 16B, the tube expands axially, forcing the tail to
9 bend as shown in FIG. 2. The tube 16B is connected to both
10 ports 60, 64 through the pressurization throttles 62, 66,
11 respectively. The throttles 62, 66 regulate the flow of fluid
12 into the pressure chambers 48, 52. Fluid flow at the chamber
13 52 is restricted more than fluid flow at the chamber 48 so
14 that pressure builds faster at the chamber 48. When the net
15 force of the spindle 34 through the pressure difference on the
16 sides of the spindle exceeds the preload of the spring 44, the
17 spindle begins to move to the chamber 52. After a very short
18 motion, the vent port 68 is opened and the fluid within the
19 pressure chamber 52 is free to escape. The pressure forces
20 then grow, forcing the spindle 34 completely to the pressure
21 chamber 52. The tube 16B is then connected to ambient
22 pressure through the pass-through line 38 and the tube 16A is
23 connected to the pressure vessel 12 through the pass-through
24 line 36.

25 As the pressure drops in the pressure chamber 48 and
26 pressure increases in the pressure chamber 52, the tube 16A
27 expands and the tube 16B contracts forcing the tail 18 to bend

1 as shown in FIG. 3. Simultaneously, the pressure of the tube
2 16B drops below the pressure of the pressure chamber 48 and
3 pressure is released back through the pressurization throttle
4 62. When the pressure drops below the preload of the spring
5 44 forcing the spindle 34 to the pressure chamber 48, the
6 spindle moves back to the pressure chamber 48. As the spindle
7 34 moves, the tube 16A is connected to ambient pressure, vents
8 and contracts while the tube 16B connects to the pressurized
9 fluid of the pressure vessel 12, pressurizing and expanding.
10 The vent passage 70 reseals and air is forced from the tube
11 16B back into the sides of the spindle 34, initiating the
12 cycle again.

13 The frequency of system oscillation is controlled by the
14 settings of the pressurization throttles 62, 66. Throttles
15 remaining wide open allow the air to rapidly pressurize the
16 sides of the spindle 34 and the device oscillates rapidly.
17 Restricted flow slows the dynamics of the valve 14. In
18 addition, residence time of the spindle 34 in its positions
19 can be controlled by adjusting the spring preload, stiffness,
20 and the throttle settings.

21 Although the valve 14 can be connected to conventional
22 linear actuators, pneumatic motors, or other devices, to
23 support the preferred embodiment, motion of the flexible
24 appendage 10 is generated through the use of the
25 circumferentially reinforced elastomeric tubes 22. The tubes
26 are described in detail in U.S. Patent 6,148,713 "Elastomeric
27 Surface Actuation System", incorporated herein by reference.

1 The thin walled elastomeric tube 22 is surrounded by the
2 constraint rings 24. When fluid is forced through the supply
3 port in the end cap 28, internal pressure forces the end caps
4 26, 28 axially and the tube 22 radially. Because expansion is
5 constrained radially by the constraint rings 24, the tube 22
6 expands in an axial direction only. If the constraint rings
7 24 are closely spaced, the elastomeric tube 22 cannot form a
8 hernia between the constraint rings and the system remains
9 stable. Two of the reinforcing tubes connected together with
10 the interconnecting members 30 can form the articulation
11 system necessary to oscillate the tail 18.

12 In view of the above detailed description, it is
13 anticipated that the invention herein will have far reaching
14 applications other than those of a flexible and oscillating
15 appendage.

16 This invention has been disclosed in terms of certain
17 embodiments. It will be apparent that many modifications can
18 be made to the disclosed apparatus without departing from the
19 invention. Therefore, it is the intent of the appended claims
20 to cover all such variations and modifications as come within
21 the true spirit and scope of this invention.